Improved Viewing Zones for Projection Type Integral Imaging 3D Display Using Adaptive Liquid Crystal Prism Array

Chih-Wei Chen, Myungjin Cho, Yi-Pai Huang, and Bahram Javidi, *Fellow, IEEE*

***Abstract*—In this paper, we present a novel projection-type 3-D integral imaging display with an adaptive liquid crystal (LC) prism array. Comparing with conventional integral imaging display, the proposed system demonstrated that the viewing zones for a projection type integral imaging display was successfully extended by time-multiplexed technique and without any mechanical movement. To the best of our knowledge, this is the first report on combining an adaptive LC prism array with the projection-type integral imaging 3-D display. The proposed display is attractive for future wide viewing zone projection-type integral imaging 3-D displays.**

***Index Terms*—Integral imaging (II), liqAuid crystal prism, 3D display, viewing zones improvement.**

I. INTRODUCTION

GLASSES-FREE three-dimensional (3D) displays have been regarded as a critical technology for next generation display applications. There are interesting works such as multiplexed-2D displays [1]–[7] and integral imaging (II) systems [8]–[18] that have been proposed. However, the multiplexed-2D type auto-stereoscopic displays only supply discrete viewpoints and special viewing zones for 3D visualization, while this method is easily implemented. To avoid these problems, the integral imaging system, has become a promising technology. Integral imaging systems use a lenslet or camera array to capture 2D images which are multiple views from a 3D scene. 3D images are then displayed through optical reconstruction from these recorded multiple 2D images with different perspectives of the 3D scene. Nevertheless, there are still some technical limitations for integral imaging systems. One of the limitations is the narrow viewing angle, which is due to the field of view (FOV) of lenslets. Some researchers had realized this problem and proposed exciting solutions as following. The MATRES [19] architecture and the curved lens array [20]–[22] were proposed to extend the oblique angles for both the pickup and the display process. The COMSAII [23] method used moving lenslet array technique to extend the FOV of the II system. And the dynamic barriers [24] method distributed the different viewing zones by tilting the barrier. However, the mechanical movement of moving lenslet array and the dynamic barriers are still an issue. Another approach without mechanical movement called elemental lens switching [25], [26] was also proposed. In this paper, we propose another approach by using a synchronized adaptive liquid crystal prism array with a projection type integral imaging 3D display. Hence, the improved viewing zones for a time multiplexed integral imaging 3D display without any mechanical movement can be achieved.

II. IMPROVED VIEWING ZONES FOR II 3D DISPLAY USING ADAPTIVE LIQUID CRYSTAL PRISM ARRAY

In this section we first describe the key device, the adaptive liquid crystal prism array. Then, the viewing zone analysis of a general projection type integral imaging display and the proposed system are illustrated. In this paper the projection type integral imaging display is used because the projection scheme could provide high quality and flipping-free 3D images for the viewers [12], [27].

A. Adaptive Liquid Crystal Prism Array

The proposed stripe type multiple electrode based liquid crystal (LC) prism array is shown in Fig. 1. The LC molecules were first aligned perpendicular to the bottom electrodes on both the top and bottom substrates (homogeneous type). Applying an operating voltage (V_1) and reference voltage (V_2) to the stripe electrodes, respectively, (i.e., V_1 for red electrodes and V_2 for gray electrodes), the effective refractive index distribution could be changed when the LC is reorienting. Thus, the incident polarized light could be refracted to different angles according to the refractive index distribution [see Fig. 1]; on the other hand, exchanging the values of operating and reference voltages, the prism could be switched to the opposite shape. The light could consequently be refracted to opposite direction. At that time, the planar electrode was always driven by reference voltage (V_2).

Manuscript received July 15, 2013; revised October 01, 2013; accepted November 25, 2013. Date of publication December 03, 2013; date of current version February 11, 2014. This work was supported in part by the National Science Council, Taiwan, under Academic Project NSC101-2221-E-009-120-MY3 and Project NSC101-2917-I-009-006. The work of B. Javidi was supported by Samsung Electronic Company.

C.-W. Chen and Y.-P. Huang are with the Department of Photonics and the Institute of Electro-Optical Engineering/Display Institute, National Chiao Tung University, 30010 Hsinchu, Taiwan. (e-mail: tedd0202.di96g@g2.nctu.edu.tw; boundshuang@mail.nctu.edu.tw).

M. Cho is with the Electrical, Electronic, and Control Engineering, Hankyong National University, Ansung 456-749, Korea (e-mail: mjcho@hknu.ac.kr).

B. Javidi is with the Electrical and Computer Engineering Department, University of Connecticut, Storrs, CT 06269 USA (e-mail: bahram@engr.uconn.edu)

Color versions of one or more of the figures are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/JDT.2013.2293272

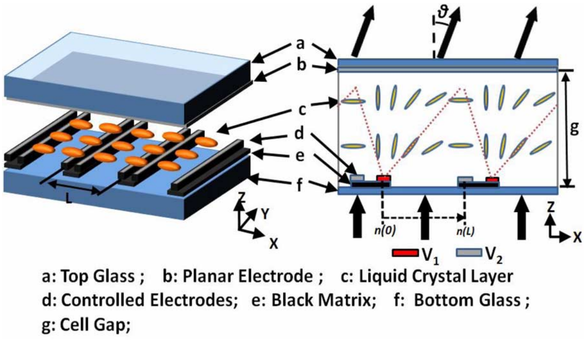

Fig. 1. Structure of multiple electrodes based liquid crystal prism array. The light could be refracted to different directions when applying driving voltages.

The refraction angle of the adaptive LC prism could be calculated by the optical path difference (Δ OPD) as follows,

$$\theta = \tan^{-1}(\Delta n \times g/L) \tag{1}$$

$$\Delta n = \frac{1}{z}\int_{0}^{z} [n(z)_0 - n(z)_L]dz \tag{2}$$

where θ is the refraction angle, g is the LC-cell gap, L is the prism width, and Δn is the refractive index difference between $n\ (L)$ and $n(0)$. The value of Δn could be controlled by changing the driving voltages on the LC cell. Accordingly, the incident light also could be refracted by a θ angle.

B. Viewing Zone Analysis and Improved Viewing Zones for Projection Type Integral Imaging 3D Display

Viewing zone (VZ) is an important factor for a 3D display. A wide viewing zone not only lets viewers have more freedom in viewing positions, but also increases the number of possible viewers. Conventional integral imaging systems included two steps. For the capturing steps, a lenslet or camera array is used to capture 3D information from a 3D scene. Then, a set of 2D elemental images that had different perspectives were recorded [28]. For the displaying steps, the captured 2D elemental images were displayed onto the lenslet array. Thus, the 3D scene could be optically reconstructed [14], [15]. The VZ for the conventional integral imaging system could be defined from the viewing angle of a lenslet as shown in Fig. 2 and (3) [12],

$$\varphi = 2\tan^{-1}(p/2f) \tag{3}$$

where φ is the viewing angle of a lenslet, p is the lenslet pitch, and f is the focal length of the lenslet, respectively. The angle φ is the maximum angle that an elemental image can be captured or displayed from its corresponding lenslet.

The projection type integral imaging 3D display can provide flipping-free images because each elemental image can be only projected onto its corresponding lenslet. Therefore, viewers do not perceive any images if they were located outside the viewing zone. However, the narrow viewing zone is an issue of this projection type 3D display.

To overcome the viewing zone limitation, we proposed a new system by combining the adaptive LC prism array with a projection type integral imaging 3D display as shown in Fig. 2. By varying the refraction angle of the adaptive LC prism array sequentially, the elemental images could be projected to different viewing positions. For instance, to obtain the left-view image, the prism array was driven to refract the light to left viewing zone; meanwhile, the elemental images were also simultaneously changed for the corresponding left-view image [see T3 in Fig. 2]. Consequently, by driving the adaptive LC prism array and synchronizing the display of the assigned elemental images in a time-multiplexed method, the viewing zones could be extended by $(\varphi + 2\theta)$ without mechanical movement.

III. EXPERIMENTS AND DISCUSSIONS

In this experiments section, the LC prism array was first fabricated and measured. The preliminary functionality of wide viewing angle for the proposed system is also demonstrated.

The design parameters of each prism are listed: prism width (L) is 45 μm, electrode width is 5 μm, small slit between two electrodes is 5 μm, and cell gap (g) is 15 μm [see Fig. 3]. The LC material we used is E7 (Merck). For the LC prism, the imperfect area called the fly-back zone [29], which comes from the characteristics of the liquid crystal, may result in the light go to undesired direction. Thus, the crosstalk issue will be induced. To suppress this phenomenon, the black matrix (BM) located under the electrodes was used to block the light passing through the fly-back zones and to approach the ideal prism shape [see Fig. 3]. Although the BM matrix could help to obtain a better prism performance, the image brightness may be decreased. Therefore, to obtain a better prism performance with narrow BM width will be the subject of a future investigation.

After fabricating the LC prism array, we applied different driving voltages on the electrodes to evaluate the functionality of the LC prism array. A white light source was normally illuminated on the LC prism array, and the capturing plane was located approximately 37 cm away from the LC prism panel. The preliminary result is shown in Table I. When applying $0\ \mathrm{V_{rms}}$ on the planar electrode, and driving voltage $\mathrm{V_1} = 2.5\ \mathrm{V_{rms}}$ and $\mathrm{V_2} = 0\ \mathrm{V_{rms}}$ on the multiple electrodes alternately, [see Fig. 1] the incident light could be refracted by a maximum refracted angle, right side 4 degrees. (i.e., the maximum refractive angle reaches at $\Delta n = 0.2$). In addition, the different refracted angles also could be obtained by applying the different driving voltages on electrodes yet a little bit diffraction issue still has to be further reduced for high quality 3D images. In detailed analysis, the diffraction was caused by the imperfect fabrication of the LC prism shape and black matrix structure. Therefore, to shorten the BM width and to make a better prism array could be the next step. Nevertheless, the diffraction did not affect our following experiment seriously. The functionality of the LC prism was proven.

We constructed the proposed prototype by combining the projection-type II system [12], [27] with the adaptive LC prism array, which is aligned in front of a lenslet array, to verify our approach. The polarizer was located in front of the projector in order to obtain polarized light. For the image content part, the 2D elemental images were generated by computer synthesized integral imaging method [30]. Each elemental image contained 30×30 pixels, and totally 34×25 elemental images were generated as shown in Fig. 4. Fig. 4(a) is the 3D scene for generating

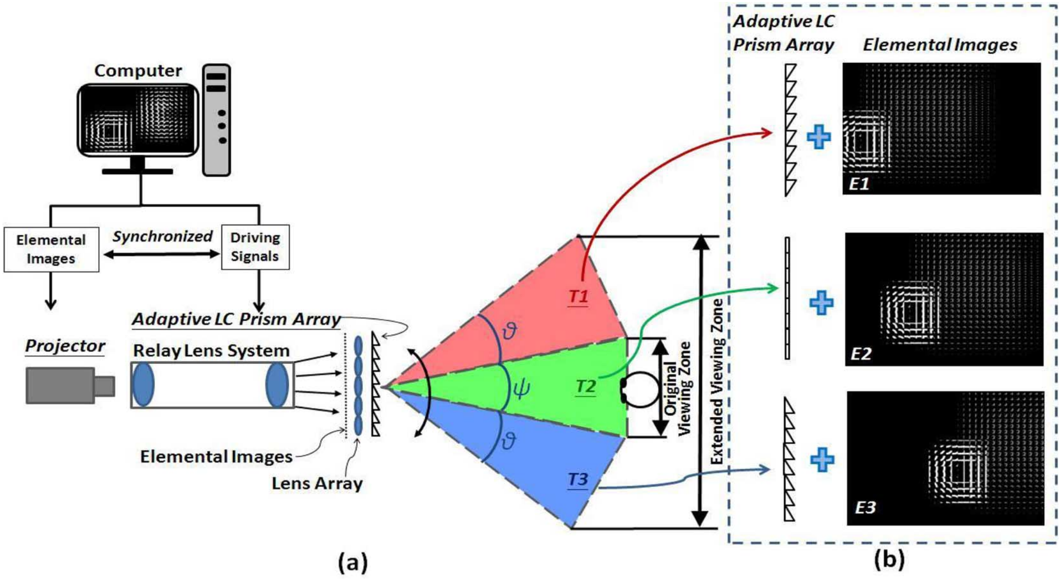

Fig. 2. (a) Scheme of the proposed time multiplexed projection type integral imaging 3D display with the adaptive LC prism array and (b) synchronized elemental images and the LC prism for different viewing zones.

TABLE I

Experimental Results With Different Projection Angles for a Normally Incident Light Source by Switching the Driving Voltages on the LC Prism Array. The Observed Plane is 37 cm Away From the Prism Array, [i.e., Plus: Right Side; Minus: Left Side (V_1 and V_2 for Corresponding Electrodes Are Illustrated in Fig. 1

Driving Voltage (Vrms)	V_1=0 V_2=2.5	V_1=0 V_2=2	V_1=0 V_2=0	V_1=2 V_2=0	V_1=2.5 V_2=0
Refraction Angle (Degree)	-4	-2	0	+2	+4

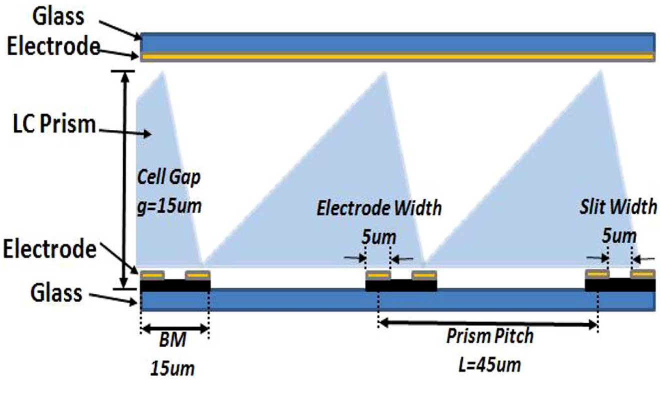

Fig. 3. Structure of proposed multiple electrode based adaptive LC prism array.

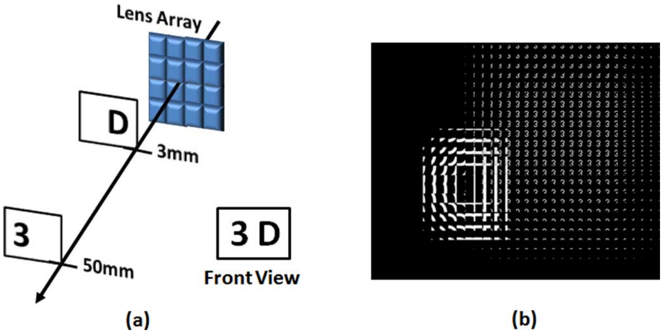

Fig. 4. (a) 3-D scene for generating elemental images and (b) an elemental images set generated from front view by computer synthesized method.

the elemental image sets. The objects "3" and "D" were placed in front of the lenslet array at approximately 50 mm and 3 mm, respectively. Fig. 4(b) is an elemental images set that was generated from the front view. Other elemental image sets for left and right viewing zones were also generated by this computer synthesized method.

Projecting the elemental images set on the lenslet array, the 3D scene could be optically reconstructed. The reconstructed results were captured by placing the camera at different viewing positions, as shown in Fig. 5. In this experiment, the size of each lenslet is 1.09 mm × 1.09 mm and its focal length is approximately 3.6mm. Thus, the viewing zone of the conventional projection type integral imaging 3D display was narrow and approximately ±8.5°. On the contrary, for the proposed 3D display, the total viewing zones could be extended horizontally to about ±12° by synchronizing the elemental image sets and the adaptive LC prism array. The experimental results clearly verified that our proposed approach could obtain 3D images with improved viewing zones. In addition, ±4.5° and ±6° views were covered for ±4° and 0° LC prism array states. Thus, we also captured the images at these viewing positions. The results

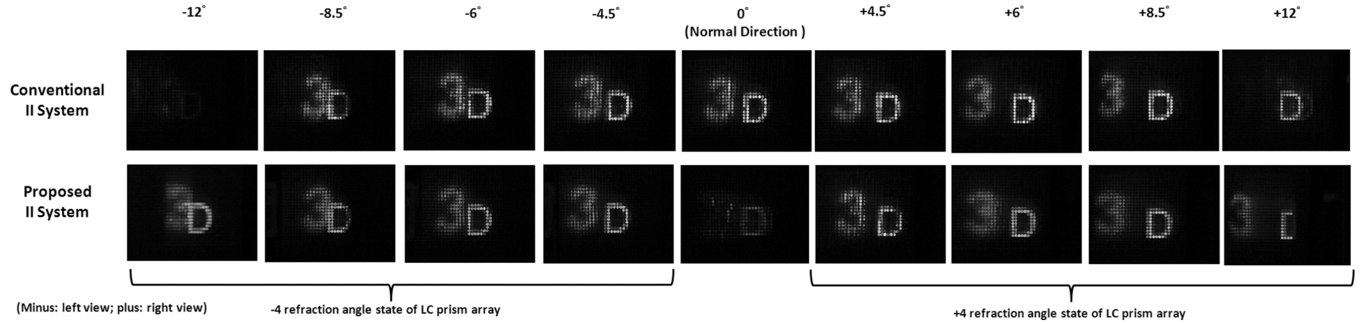

Fig. 5. Captured images from different viewing directions of conventional and proposed projection type integral imaging display.

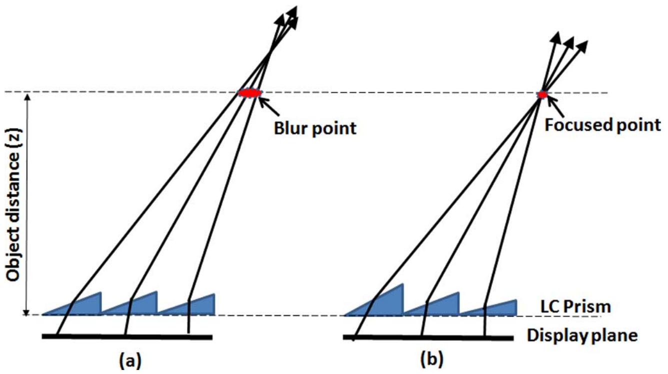

Fig. 6. Illustration of image distortion results from (a) the nonuniform viewing angle expansion for uniform LC prism array and (b) the proposed method, the nonuniform LC prism array for uniform viewing angle expansion.

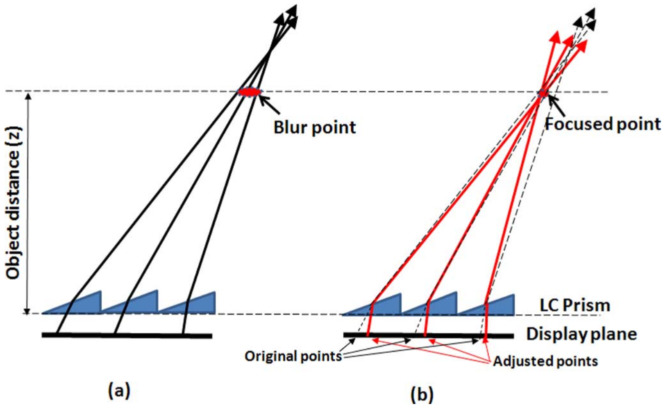

Fig. 7. Illustration of image distortion results from (a) the nonuniform viewing angle expansion for uniform LC prism array and (b) the proposed calibrating method on the elemental images for remedying the deformation issue.

illustrate that the same images also could be observed under different LC prism array states [see Fig. 5]. Besides, in order to approach wider refraction angle of the LC prism array, we propose using different LC materials such as the high birefringence LC (HB-LC) [31], [32]. Hence, the viewing zones for the projection type II 3D display could be further extended. This new proposed method could be the subject of a future investigation.

Although the preliminary functionality of our proposed system has been demonstrated, the 3D image distortion and the response time of the LC prism array still have to be discussed. First, for the 3D image distortion part, the word, "3", which was located at 50 mm away from the II display, became blurred when observed at large viewing angles $(\pm 12^\circ)$ [see Fig. 5]. This was because the light could not be focused well due to the non-uniform viewing angle expansion for prisms as shown in Fig. 6(a). Thus, the reconstructed 3D object at the image plane was blurred. We propose two methods to improve this issue. First, using the non-uniform distribution LC prism array, the blurring image at a specific distance can be improved, as shown in Fig. 6(b). By varying each LC prism profile individually, the non-uniform viewing angle expansion of prism might be eliminated hence the image distortion for a specific distance could be reduced. However, the complexity of the LC prism array might be increased to eliminate the distortions in 3D reconstructed images. This method could be used to eliminate this distortion for a distance. Hence, the second solution could be the image processing method, or the calibrating method. By calculating the deformation of the 3D images at different distances, the information of each elemental image could be adjusted. Thus, the deformation of the 3D images could be calibrated [see Fig. 7].

For the response time of the LC prism array part, the response time of the proposed LC prism array is 200 ms $(\tau_{\mathrm{on}} + \tau_{\mathrm{off}})$. Therefore, using fast response LC materials such as blue phase LC [33], [34] or Ferroelectric LC [35], [36] to be the LC material in the LC prism, the response time could be shortened. These new proposed methods could be the next topic.

Not only the horizontal viewing zones, but also the vertical viewing zones of the projection type II 3D display could be improved by the two crossed LC prism array panels [see Fig. 8], or by integrated dual-crossed multiple electrode based LC prism array [see Fig. 9]. For the former method, the two stripe type LC prism array panels were attached together and perpendicular to each other. A 1/2 wave plate, whose optical axis is 45° correspond to the x-direction, was sandwiched between the two LC prism panels. Therefore, when driving the two LC prism panels sequentially, both horizontal and vertical viewing zones could be extended using the proposed system. Another approach is to use an integrated dual-crossed multiple electrodes structure as shown in Fig. 9. For instance, applying the alternated operating voltage (V_1) and reference voltage (V_2) on the bottom multiple electrodes alternately, and reference voltage on all the top multiple electrodes, a LC prism array could be obtained on y-direction distribution; similarly, a LC prism array distributed on x-direction also could be obtained when applying the alternated operating voltage (V_1) and reference voltage (V_2) on

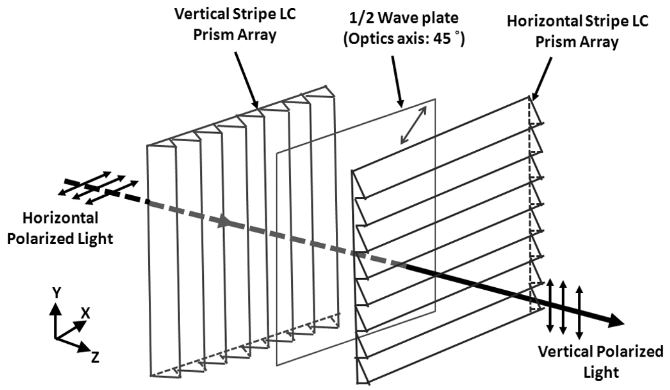

Fig. 8. Scheme of dual LC prism array for increasing both horizontal and vertical viewing zones. A half wave plate was used to rotate the direction of polarization.

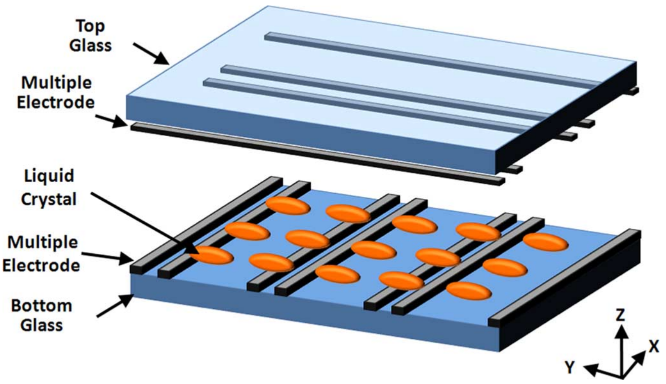

Fig. 9. Integrated dual-crossed multiple electrode-based LC prism array.

the top multiple electrodes alternately, and reference voltage on all the bottom multiple electrodes. Consequently, the improved viewing zones for both horizontal and vertical directions could be achieved.

IV. CONCLUSION

Integral imaging systems are very promising for 3D displays. Their viewing zones can be improved with additional benefits to their overall performance. In this paper, we proposed an adaptive LC prism array to electronically refract the corresponding elemental images by time multiplexed technique Therefore, the improved viewing zones for a projection type integral imaging 3D display without any mechanical movement could be achieved. The experimental results show that the horizontal viewing zones are successfully extended comparing with the conventional projection type integral imaging display. The viewing zones could be further extended by using the HB-LC materials as described in the paper. We also proposed that both the horizontal and vertical viewing zones could be extended by using two stripe type LC prism array panels, or by using the integrated dual-crossed multiple electrode based LC prism array panels. The proposed 3D display has potential for future integral imaging 3D displays.

ACKNOWLEDGMENT

The authors would like to thank X. Xiao, University of Connecticut, Dr. C. H. Tsai, ITRI, Taiwan, and Y. R. Su, NCTU, Taiwan, for their valuable discussion and technical support. The second author contributes to the paper by the same work as the first author.

REFERENCES

[1] J. Y. Son and B. Javidi, "Three-dimensional image methods based on multi-view images," *J. Display Technol.*, vol. 1, no. 1, pp. 125–140, Sep. 2005.

[2] W. Maphepo, Y. P. Huang, and H. P. D. Shieh, "Enhancing the brightness of parallax barrier based 3D flat panel mobile displays without compromising power consumption," *J. Display Technol.*, vol. 6, no. 2, pp. 60–62, Feb. 2010.

[3] Y. Takaki, "Multi-view 3-D display employing a flat-panel display with slanted pixel arrangement," *J. Soc. Inf. Disp.*, vol. 18, pp. 476–482, 2010.

[4] J. Y. Son, B. Javidi, S. Yano, and K. Choi, "Recent developments in 3D imaging technologies," *J. Display Technol.*, vol. 6, no. 10, pp. 394–403, Oct. 2010.

[5] Y. P. Huang, L. Y. Liao, and C. W. Chen, "2-D/3-D switchable autostereoscopic display with multi-electrically driven liquid-crystal (MeD-LC) lenses," *J. Soc. Inf. Disp.*, vol. 18, pp. 642–646, 2010.

[6] Y. P. Huang, C. W. Chen, and Y. C. Huang, "Superzone Fresnel liquid crystal lens for temporal scanning auto-stereoscopic display," *J. Display Technol.*, vol. 8, no. 11, pp. 650–655, Nov. 2012.

[7] C. W. Chen, Y. P. Huang, and P. C. Chen, "Dual direction overdriving method for fast switching liquid crystal lens on 2D/3D switchable autostereoscopic display," *J. Display Technol.*, vol. 8, no. 10, pp. 559–561, Oct. 2012.

[8] G. Lippmann, "La photographie integrale," *C. R. Acad. Sci. Paris Ser. IV*, vol. 146, pp. 446–451, 1908.

[9] L. Yang, M. McCornick, and N. Davies, "Discussion of the optics of a new 3-D imaging system," *Appl. Opt.*, vol. 27, pp. 4529–4534, 1988.

[10] H. Hoshino, F. Okano, H. Isono, and I. Yuyama, "Analysis of resolution limitation of integral photography," *J. Opt. Soc. Amer. A*, vol. 15, pp. 2059–2065, 1998.

[11] F. Okano, J. Arai, K. Mitani, and M. Okui, "Real-time integral imaging based on extremely high resolution video system," *Proc. IEEE*, vol. 94, no. 3, pp. 490–501, Mar. 2006.

[12] A. Stern and B. Javidi, "Three-dimensional image sensing, visualization, and processing using integral imaging," *Proc. IEEE*, vol. 94, no. 3, pp. 591–607, Mar. 2006.

[13] R. Ponce-Diaz, R. R. Martinez-Cuenca, M. Martinez-Corral, B. Javidi, and Y. Son, "Digital magnification of three-dimensional integral images," *J. Display Technol.*, vol. 2, no. 3, pp. 284–291, Sep. 2006.

[14] R. Martinez-Cuenca, G. Saavedra, M. Martinez-Corral, and B. Javidi, "Progress in 3-D multiperspective display by integral imaging," *Proc. IEEE*, vol. 97, no. 6, pp. 1067–1077, Jun. 2009.

[15] J. Arai, F. Okano, M. Kawakita, M. Okui, Y. Haino, M. Yoshimura, M. Furuya, and M. Sato, "Integral three-dimensional television using a 33-megapixel imaging system," *J. Display Technol.*, vol. 6, no. 10, pp. 422–430, Oct. 2010.

[16] M. Cho, M. Daneshpanah, I. Moon, and B. Javidi, "Three-dimensional optical sensing and visualization using integral imaging," *Proc. IEEE*, vol. 99, no. 4, pp. 556–575, Apr. 2011.

[17] M. Cho and B. Javidi, "Optimization of 3D integral imaging system parameters," *J. Display Technol.*, vol. 8, no. 6, pp. 357–360, Jun. 2012.

[18] J. S. Jang and B. Javidi, "Improved viewing resolution of 3-D integral imaging with nonstationary micro-optics," *Opt. Lett.*, vol. 27, pp. 324–326, 2002.

[19] R. Martinez-Cuenca, H. Navaarro, G. Saavedra, B. Javidi, and M. Martinez-Corral, "Enhanced viewing-angle integral imaging by multiple-axis telecentric relay system," *Opt. Exp.*, vol. 15, pp. 16255–16260, 2007.

[20] Y. Kim, J. Park, H. Choi, S. Jung, S. Min, and B. Lee, "Viewing-angle-enhanced integral imaging system using a curved lens array," *Opt. Exp.*, vol. 12, pp. 421–429, 2004.

[21] J. S. Jang and B. Javidi, "Depth and size control of three-dimensional images in projection integral imaging," *Opt. Exp.*, vol. 12, pp. 3778–3790, 2004.

[22] J. S. Jang and B. Javidi, "Very-large scale integral imaging (VLSII) for 3D display," *Opt. Eng.*, vol. 44, p. 014001, 2004.

[23] A. Stern and B. Javidi, "3-D computational synthetic aperture integral imaging (COMPSAII)," *Opt. Exp.*, vol. 11, pp. 2446–2451, 2003.

[24] H. Choi, S. Min, S. Jung, J. Park, and B. Lee, "Multiple-viewing-zone integral imaging using dynamic barrier array for 3D display," *Opt. Exp.*, vol. 11, pp. 927–932, 2004.

[25] B. Lee, S. Jung, and J. Park, "Viewing-angle-enhanced integral imaging by lens switching," *Opt. Lett.*, vol. 27, pp. 818–820, 2002.

[26] S. Jung, J. Park, H. Choi, and B. Lee, "Viewing-angle-enhanced integral three-dimensional imaging along all directions without mechanical movement," *Opt. Exp.*, vol. 11, pp. 1346–1356, 2003.

[27] J. S. Jang and B. Javidi, "Three-dimensional projection integral imaging using micro-convex-mirror arrays," *Opt. Exp.*, vol. 12, pp. 1077–1086, 2004.

[28] K. Yamamoto, T. Mishina, R. Oi, T. Senoh, and M. Okui, "Cross talk elimination using an aperture for recording elemental images of integral photography," *J. Opt. Soc. Amer. A*, vol. 26, pp. 680–690, 2009.

[29] B. Apter, U. Efron, and E. B. Treidel, "On the fringing-field effect in liquid crystal beam-steering devices," *Appl. Opt.*, vol. 43, pp. 11–19, 2004.

[30] J.-S. Jang, F. Jin, and B. Javidi, "Three-dimensional integral imaging with large depth of focus by use of real and virtual image fields," *Opt. Lett.*, vol. 28, pp. 1421–1423, 2003.

[31] S. Gauza, H. Wang, C. H. Wen, S. T. Wu, A. J. Seed, and R. Dabrowski, "High birefringence isothiocyanato tolane liquid crystals," *Jpn. J. Appl. Phys.*, vol. 42, pp. 3463–3466, 2003.

[32] S. Gauza, C. H. Wen, S. T. Wu, N. Janarthanan, and C. S. Hsu, "Super high birefringence isothiocyanato biphyenyl-bistolane liquid crystals," *Jpn. J. Appl. Phys.*, vol. 43, pp. 7634–7638, 2004.

[33] K. M. Chen, S. Gauza, H. Xianyu, and S. T. Wu, "Submillisecond gray-level response time of polymer-stablized blue-phase liquid crystal," *J. Display Technol.*, vol. 6, no. 2, pp. 49–51, Feb. 2010.

[34] K. M. Chen, S. Gauza, H. Xianyu, and S. T. Wu, "Hysteresis effects in blue-phase liquid crystals," *J. Display Technol.*, vol. 6, no. 8, pp. 318–322, Aug. 2010.

[35] N. A. Clark and S. T. Lagerwall, "Submicrosecond bistable electro-optic switching in liquid crystal," *Appl. Phys. Lett.*, vol. 36, pp. 899–901, 1980.

[36] X. H. Li, A. Muruuski, A. Muravsky, P. Z. Xu, H. L. Cheung, and V. G. Chgrinov, "Grayscale generation and stabilization in ferroelectric liquid crystal display," *J. Display Technol.*, vol. 3, no. 3, pp. 273–279, Sep. 2007.

Chih-Wei Chen received the B.S. degree from Department of Mechatronics Engineering, National Changhua University of Education, Changhua, Taiwan, in 2007, and is currently working toward the Ph.D. degree from the Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu, Taiwan. He was a visiting scholar at Tokyo University of Agriculture and Technology in 2011, and he is also a visiting scholar at University of Connecticut in 2012, respectively. His current research is including high image-quality LCDs, 3D display system, optics system design, and liquid crystal device design.

Myungjin Cho received the B.S. and M.S. degrees in telecommunication engineering from Pukyong National University, Pusan, Korea, in 2003 and 2005, and the M.S. and Ph.D. degrees in electrical and computer engineering from the University of Connecticut, Storrs, CT, USA, in 2010 and 2011, respectively. He is the assistant professor at Hankyong National University in Korea. He worked as a researcher at Samsung Electronics in Korea from 2005 to 2007. His research interests are areas of 3D display, 3D signal processing, 3D biomedical imaging, 3D photon counting imaging, 3D information security, 3D object tracking, and 3D underwater imaging.

Yi-Pai Huang received the B.S. degree from National Cheng Kung University in 1999, and the Ph.D. degree in electro-optical engineering from National Chiao Tung University in 2004. He is currently an full-time associate professor in the Department of Photonics & Display Institute, National Chiao Tung University, Taiwan. He is also is a visiting associate professor of Cornell University, Ithaca, NY, USA, from 2011 to 2012. Additionally, he is the secretary general of SID Taipei Chapter, and Chair of Applied-Vision program sub-committee of SID. His expertise includes 3D Display and Interactive Technologies, Display Optics and Color science, Micro-optics. In the above-mentioned research, he have so far published more than 110 international journal and conference papers (including the 57 SID Conference Papers and 10 invited talks), and have obtained 25 granted patents, with another 48 patents currently publicly available. In addition, he received the SID's distinguished paper award (2001, 2004, and 2009). Other important awards include 2011 Taiwan National Award of Academia Inventor, 2010 Advantech Young Professor Award, 2009 Journal-SID: Best paper of the Year Award, and 2005 Golden Dissertation Award of Acer Foundation.

Bahram Javidi (S'82–M'83–SM'96–F'98) received the B.S. degree from George Washington University, Washington, DC, and the M.S. and Ph.D. degrees from the Pennsylvania State University, University Park, all in electrical engineering. He is the Board of Trustees Distinguished Professor at the University of Connecticut. He has over 760 publications, including over 340 peer reviewed journal article, over 360 conference proceedings, including over 110 Plenary Addresses, Keynote Addresses, and invited conference papers. His papers have been cited 10000 times according to the citation index of *WEB of Science* $(h\text{-}index = 52)$. He is a co author on nine best paper awards.

Dr. Javidi is Fellow of seven national and international professional scientific societies, including American Institute for Medical and Biological Engineering (AIMBE), Optical Society of America (OSA), and SPIE. In 2010, he was the recipient of The George Washington University's Distinguished Alumni Scholar Award, University's highest honor for its alumni in all disciplines. In 2008, he received a Fellow award by John Simon Guggenheim Foundation. He received the 2008 IEEE Donald G. Fink prized paper award among all (over 130) IEEE Transactions, Journals, and Magazines. In 2007, The Alexander von Humboldt Foundation awarded Dr. Javidi with Humboldt Prize for outstanding US scientists. He received the Technology Achievement Award from the International Society for Optical Engineering (SPIE) in 2008. In 2005, he received the Dennis Gabor Award in Diffractive Wave Technologies from the SPIE. He was the recipient of the IEEE Lasers and Electro-optics Society (IEEE Photonics) Distinguished Lecturer Award twice in 2003–2004 and 2004–2005. He was awarded the IEEE Best Journal Paper Award from IEEE Transactions on Vehicular Technology twice in 2002 and 2005. Early in his career, the National Science Foundation named Prof. Javidi a Presidential Young Investigator and he received The Engineering Foundation and the Institute of Electrical and Electronics Engineers (IEEE) Faculty Initiation Award. He was selected in 2003 as one of the nation's top 160 engineers between the ages of 30–45 by the National Academy of Engineering (NAE) to be an invited speaker at The Frontiers of Engineering Conference which was co-sponsored by The Alexander von Humboldt Foundation. He is an alumnus of the Frontiers of Engineering of The National Academy of Engineering since 2003. He is on the Editorial Board of the PROCEEDINGS OF THE IEEE [ranked #1 among all electrical engineering journals], and he was on the founding board of editors of IEEE/OSA JOURNAL OF DISPLAY TECHNOLOGY.